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Du et al.

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(54) **FIELD EMISSION CATHODE AND FIELD EMISSION DEVICE**

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Jul. 10, 2014 (CN) 2014 1 0327705

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H01J 3/02	(2006.01)
H01J 9/02	(2006.01)

(52) **U.S. Cl.**

CPC ***H01J 1/304*** (2013.01); ***H01J 3/021*** (2013.01); ***H01J 9/025*** (2013.01); *H01J 2201/30469* (2013.01); *H01J 2203/028* (2013.01); *H01J 2203/0268* (2013.01); *H01J 2203/0272* (2013.01); *H01J 2203/0284* (2013.01); *H01J 2203/0288* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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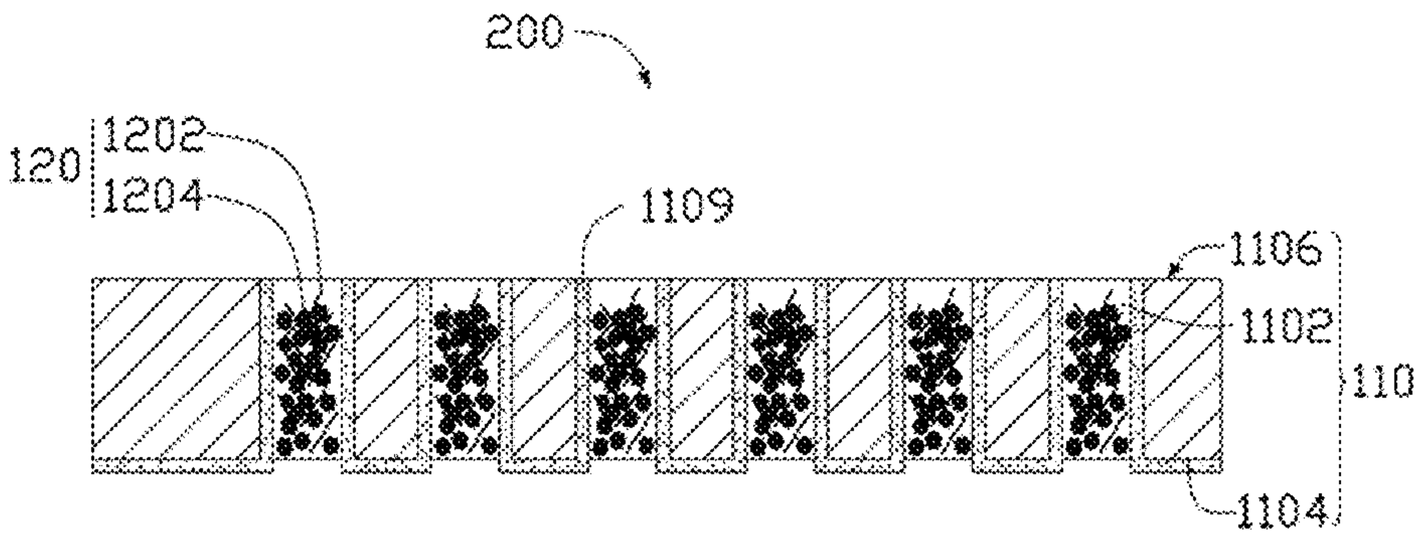
(57) **ABSTRACT**

The disclosure relates to a field emission cathode. The field emission cathode includes a microchannel plate, a cathode electrode and a number of cathode emitters. The microchannel plate is an insulative plate and includes a first surface and a second surface opposite to the first surface. The microchannel plate defines a number of holes extending through the microchannel plate from the first surface to the second surface. The cathode electrode is located on the first surface. The number of cathode emitters are filled in the number of holes and electrically connected with the cathode electrode.

20 Claims, 21 Drawing Sheets



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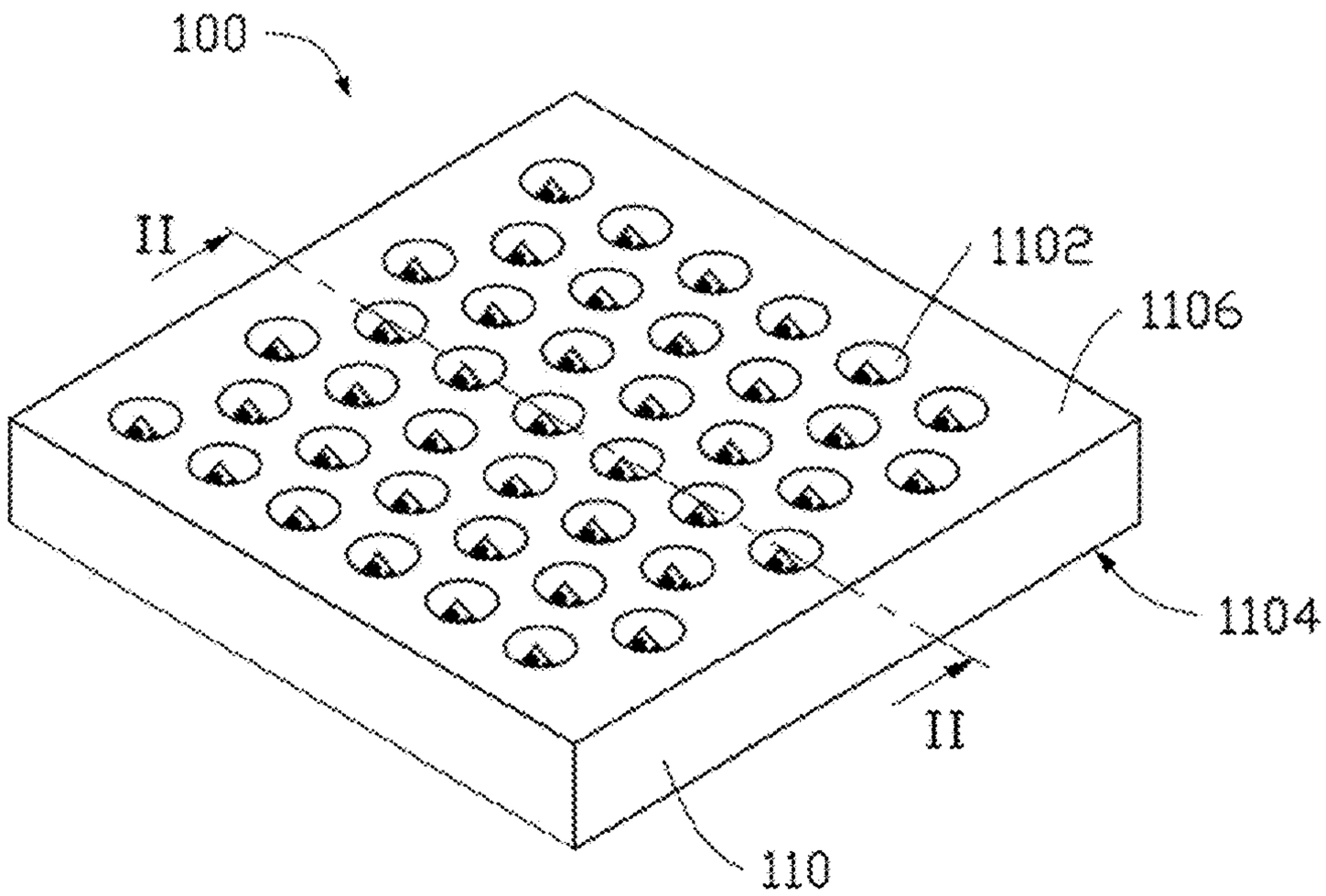


FIG. 1

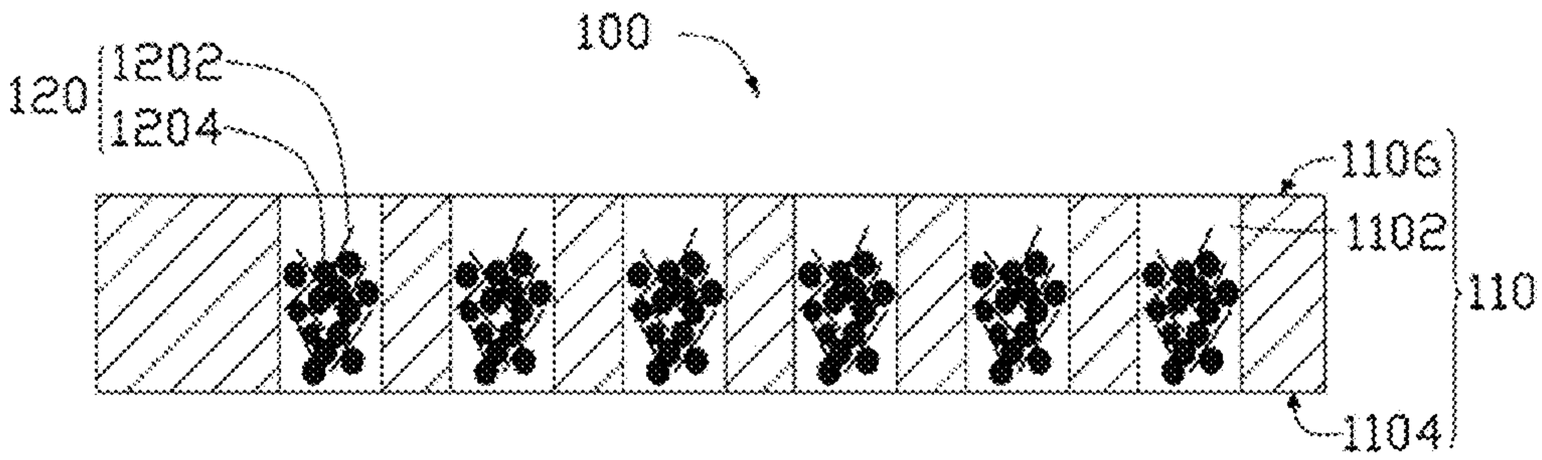


FIG. 2

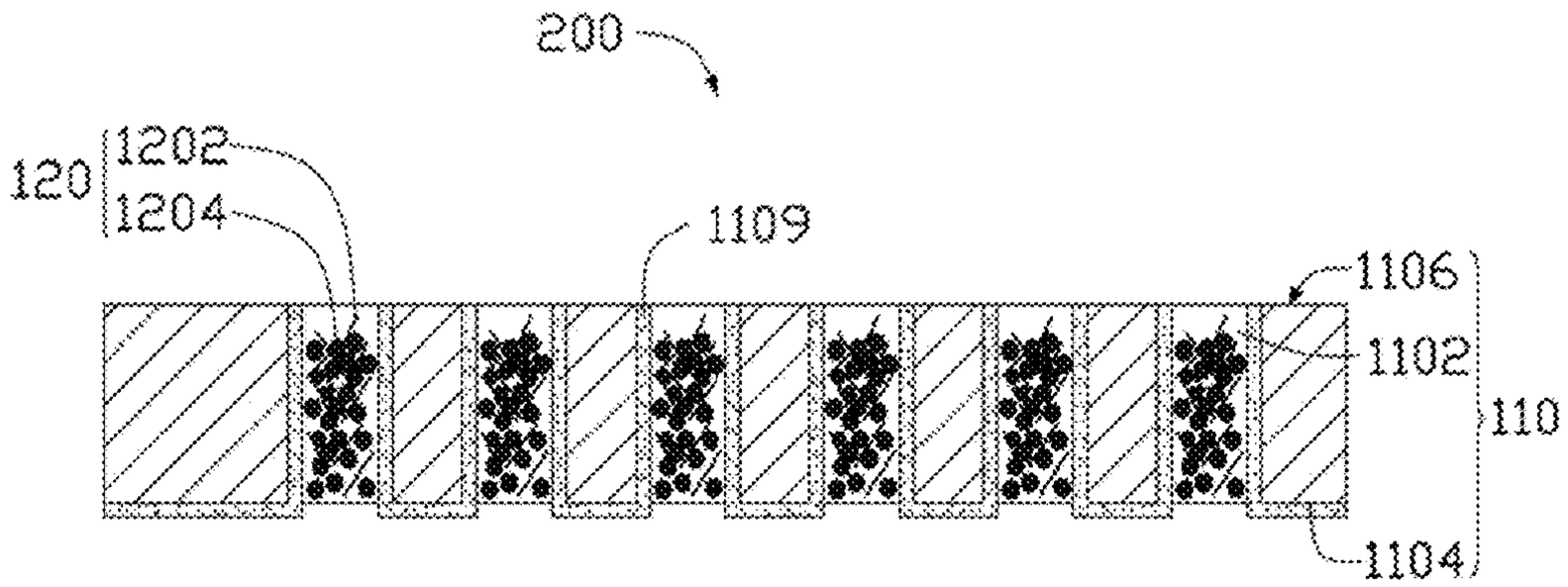


FIG. 3

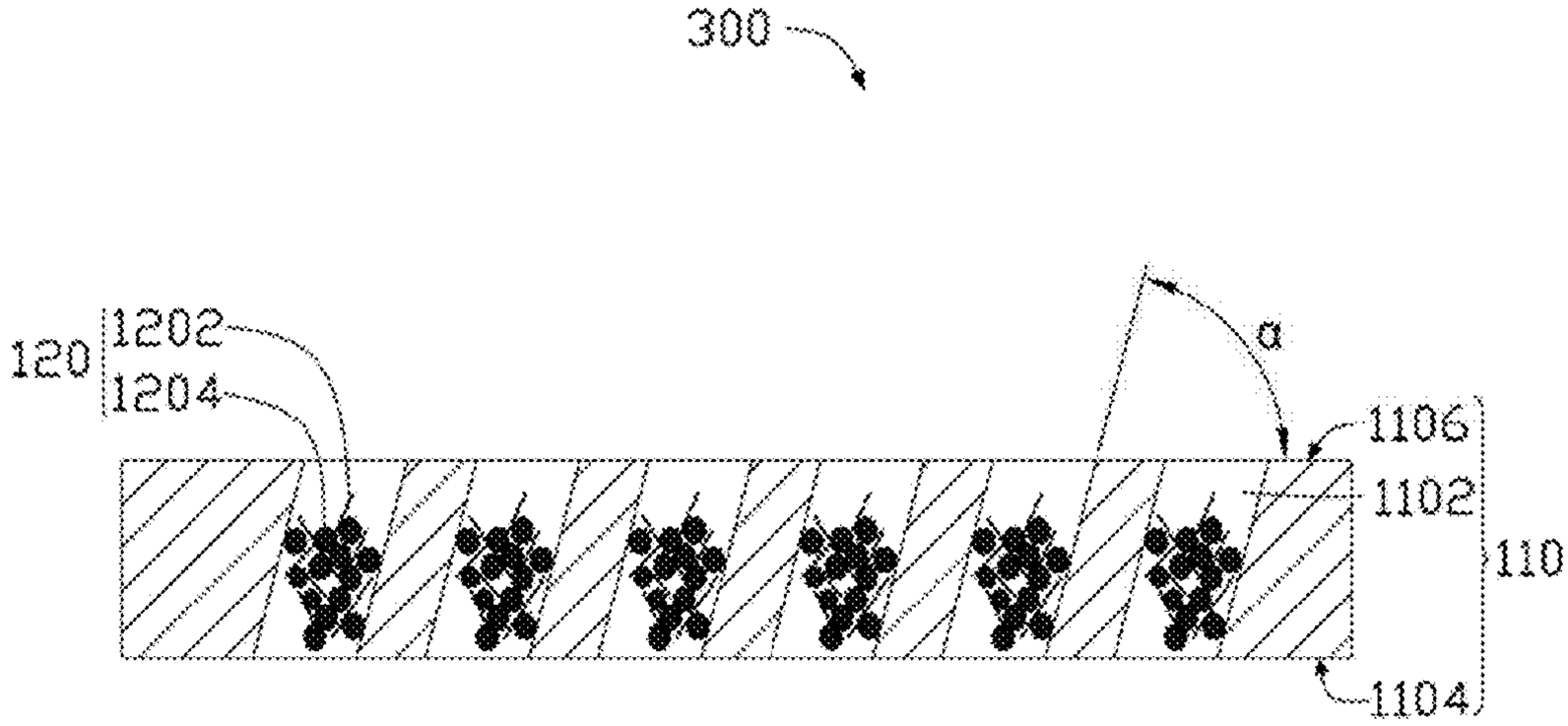


FIG. 4

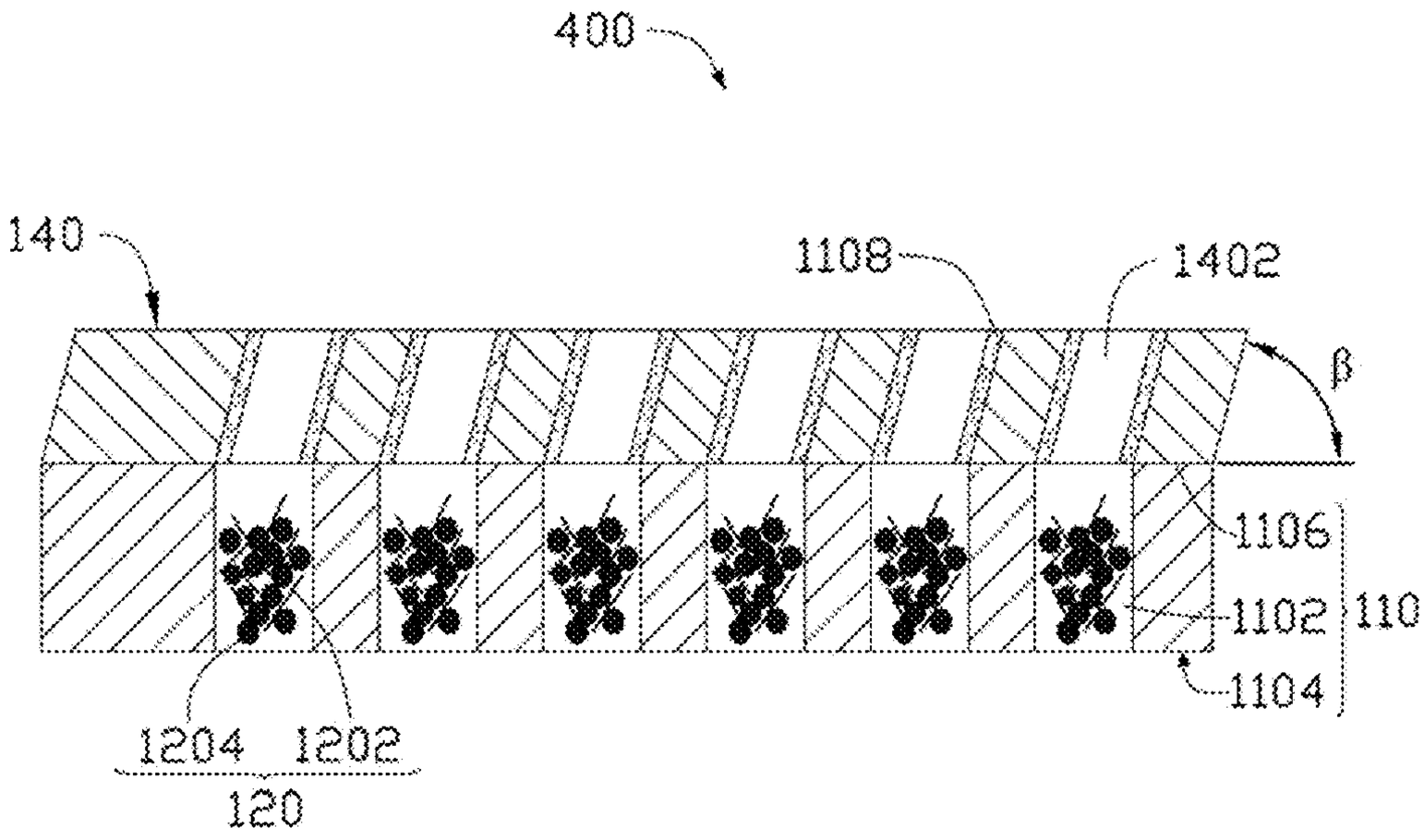


FIG. 5

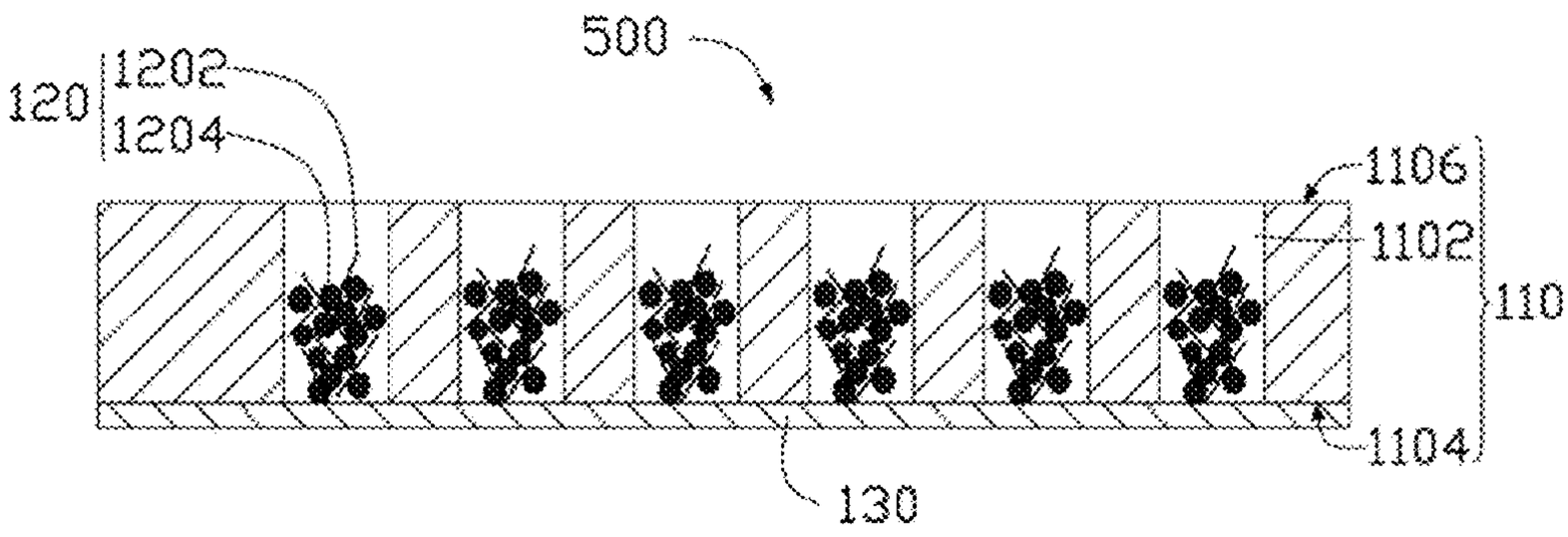


FIG. 6

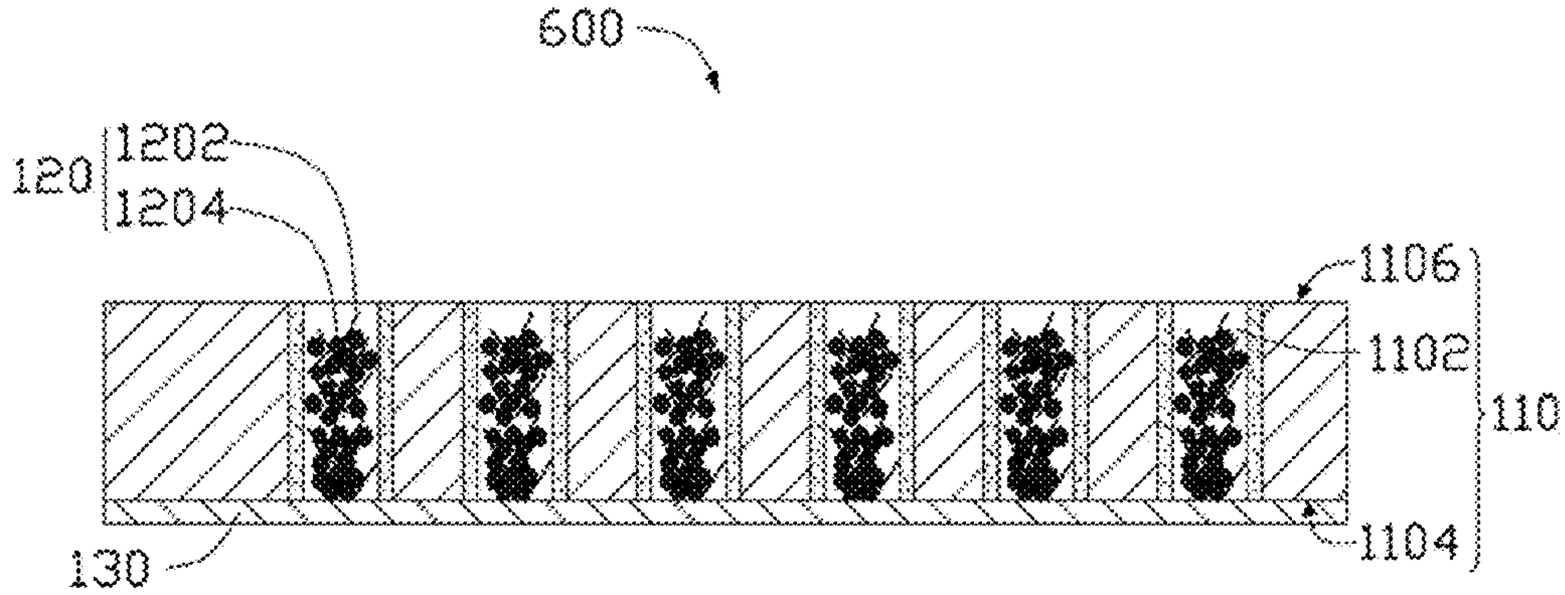


FIG. 7

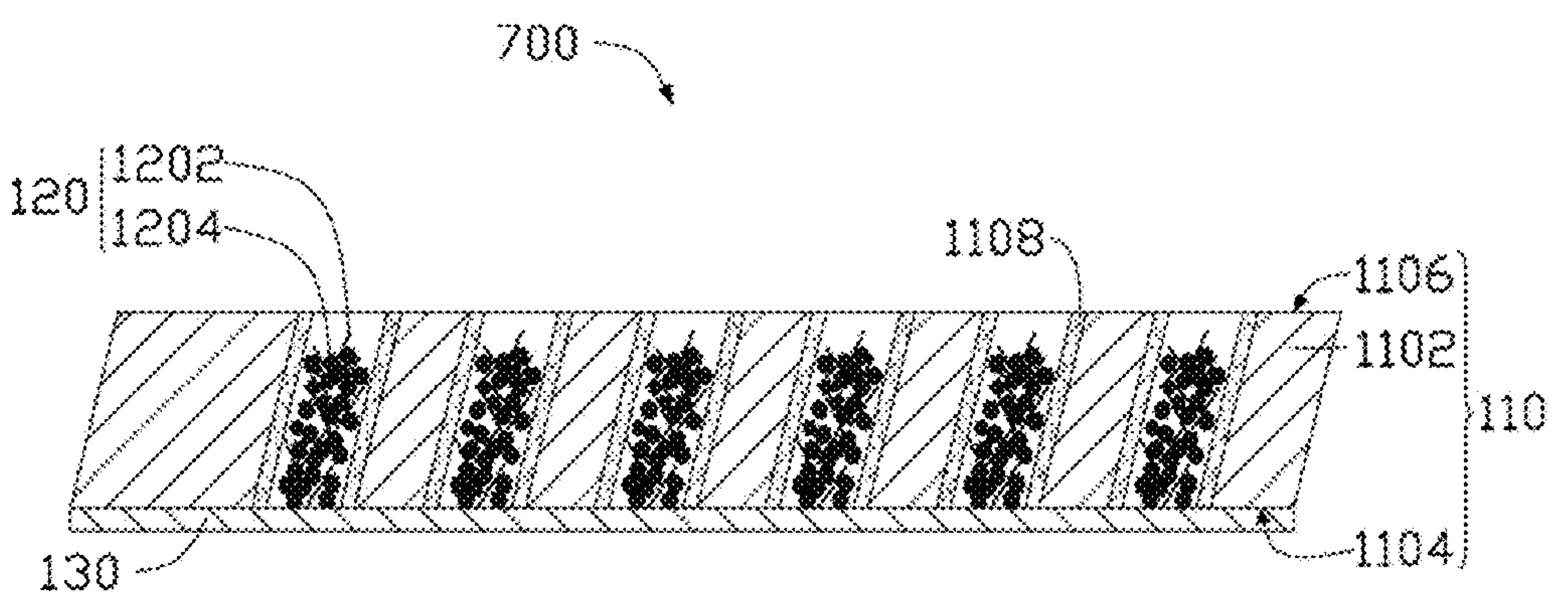


FIG. 8

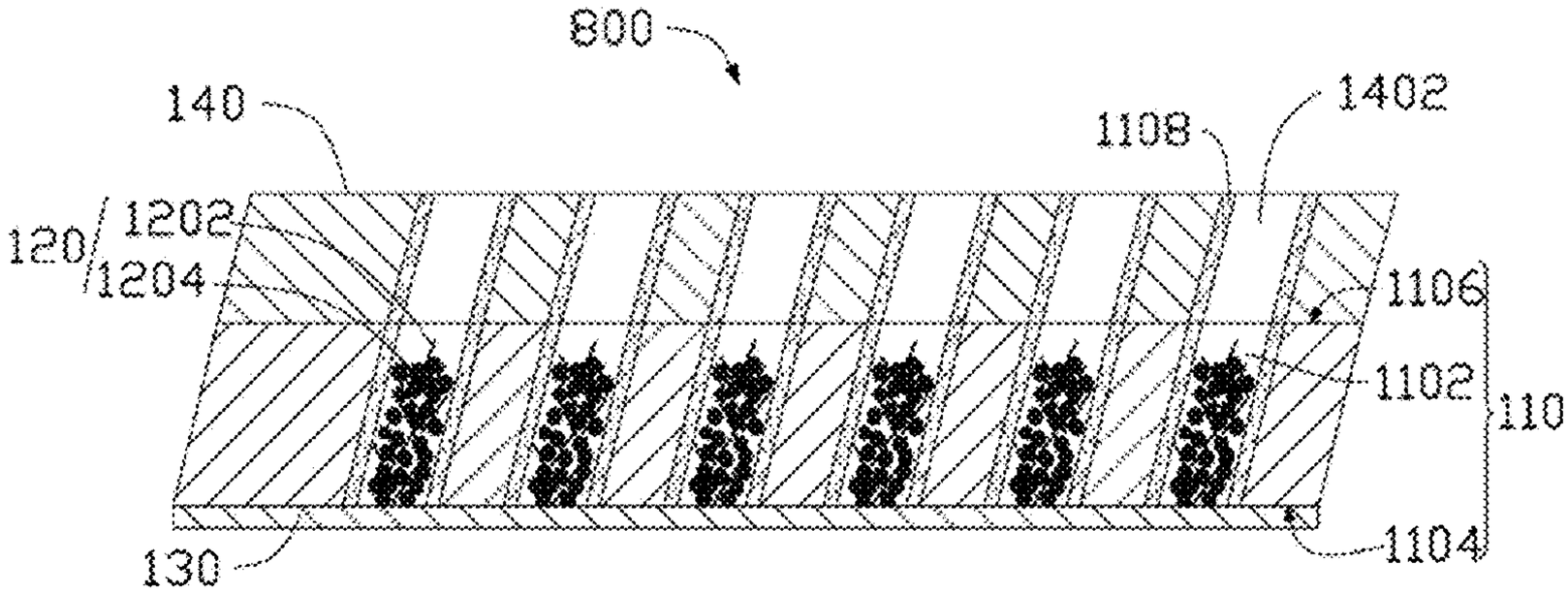


FIG. 9

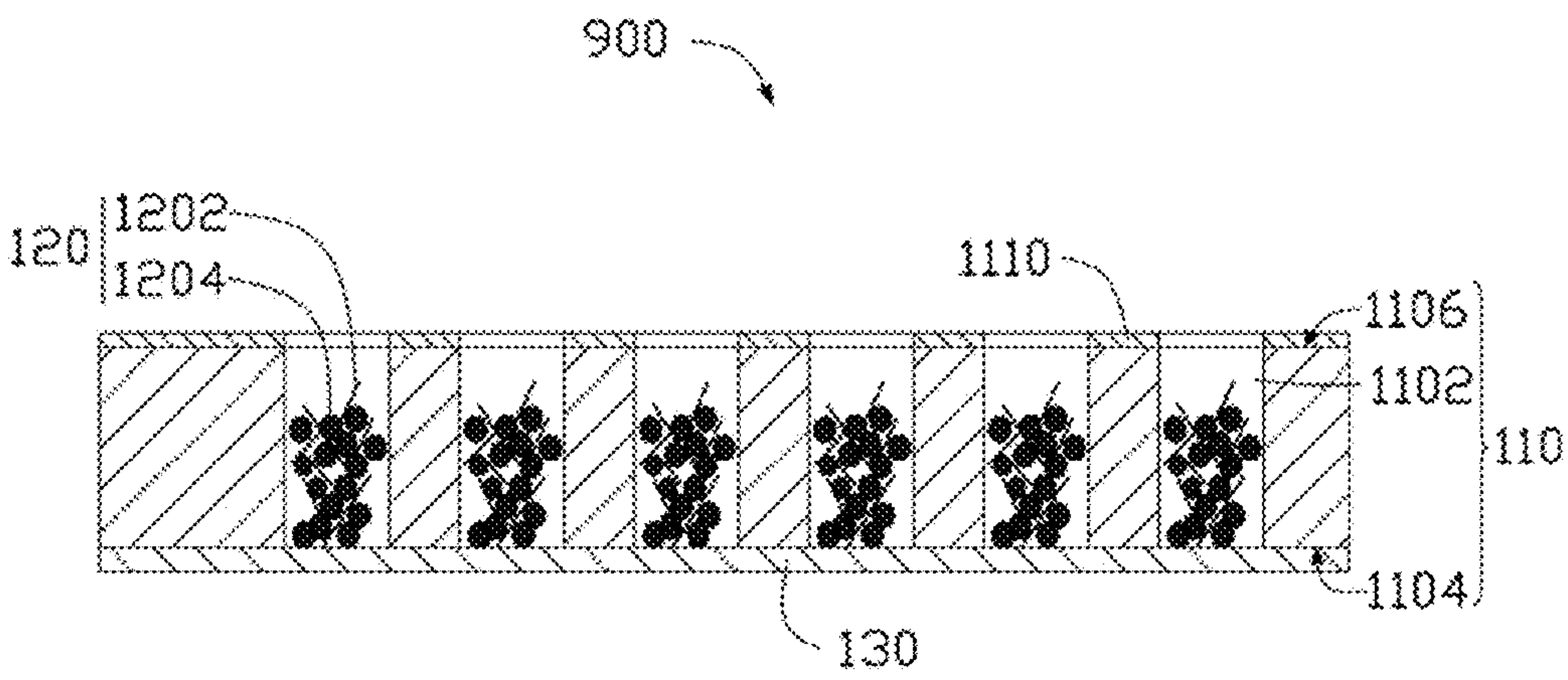


FIG. 10

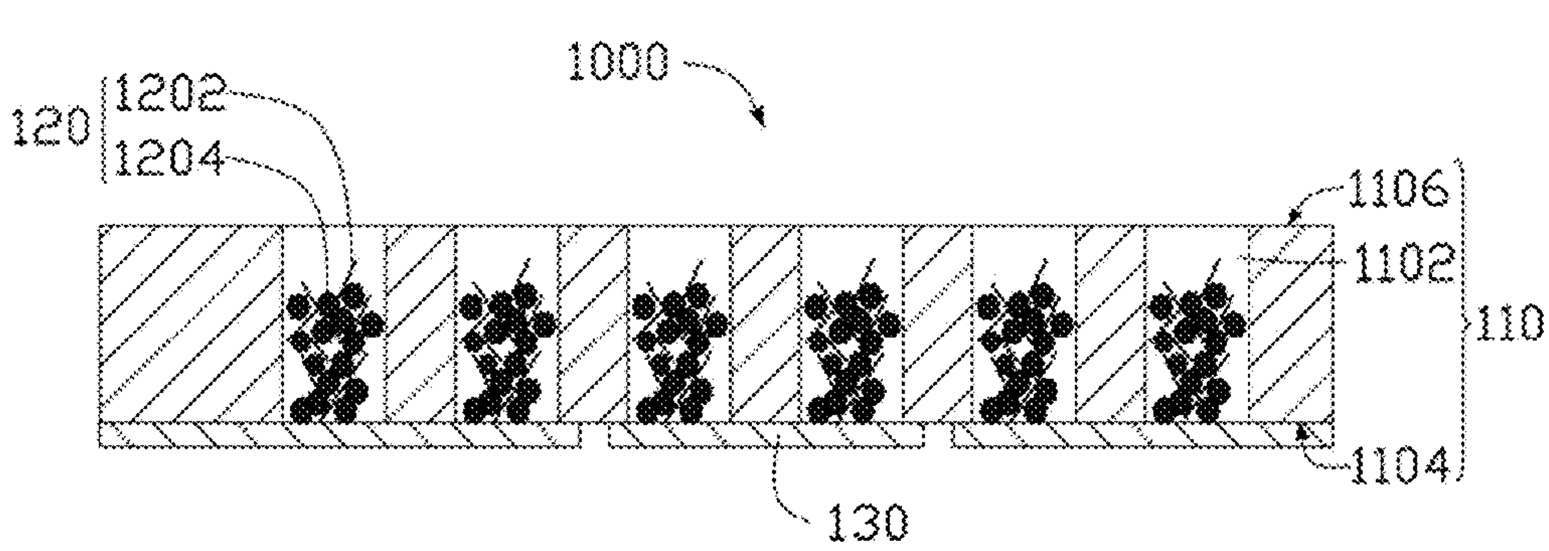


FIG. 11

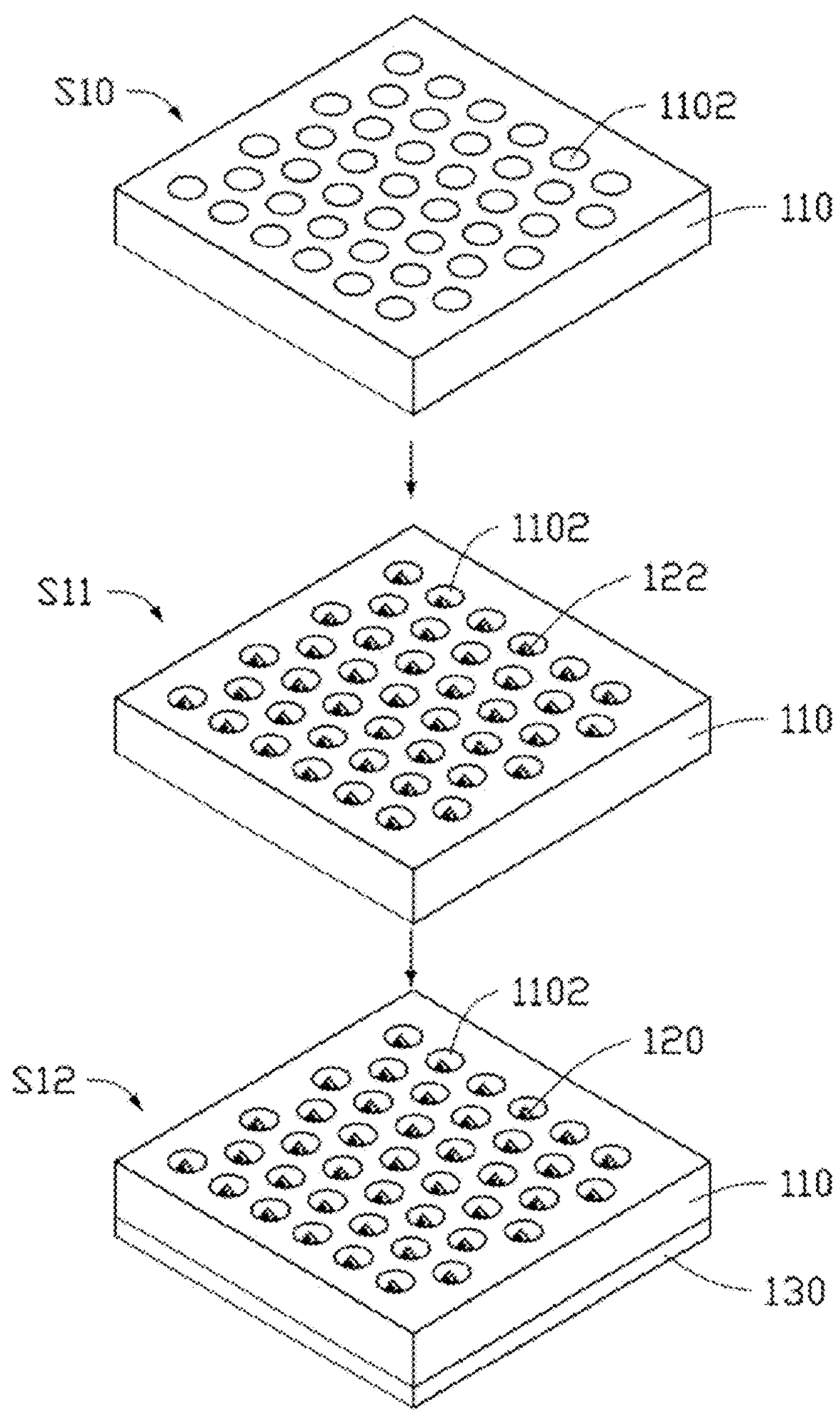


FIG. 12

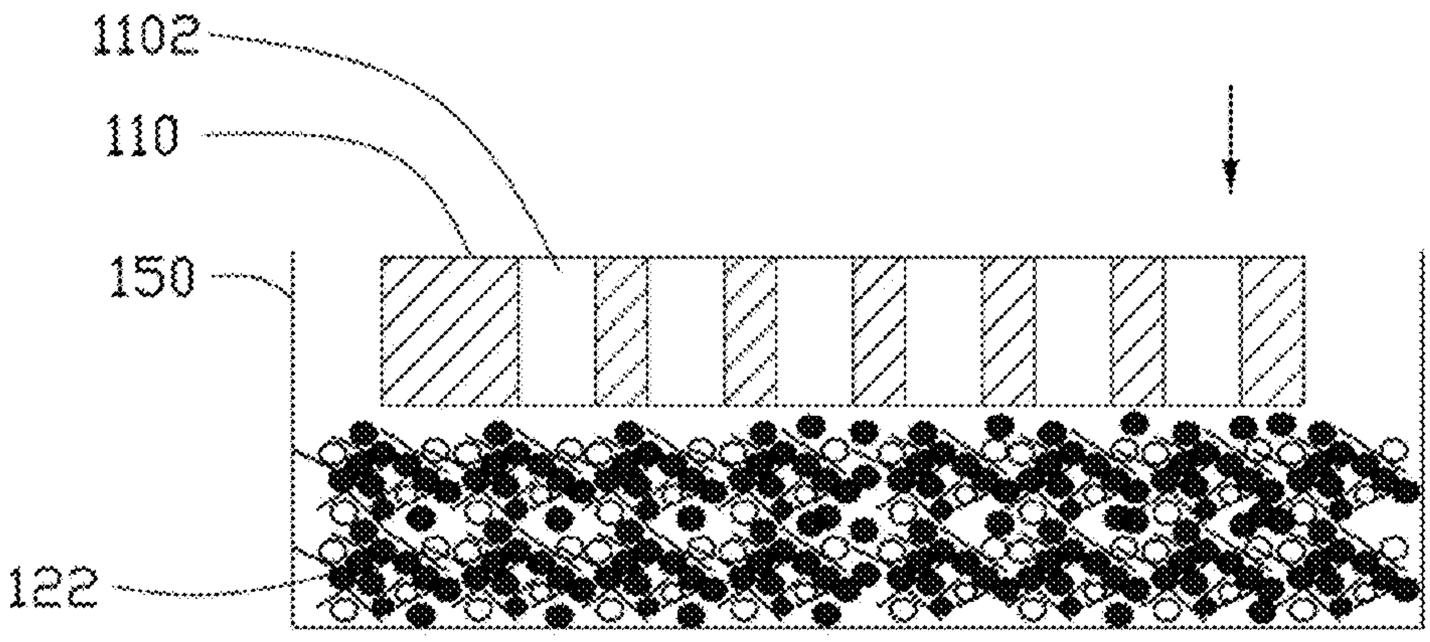


FIG. 13

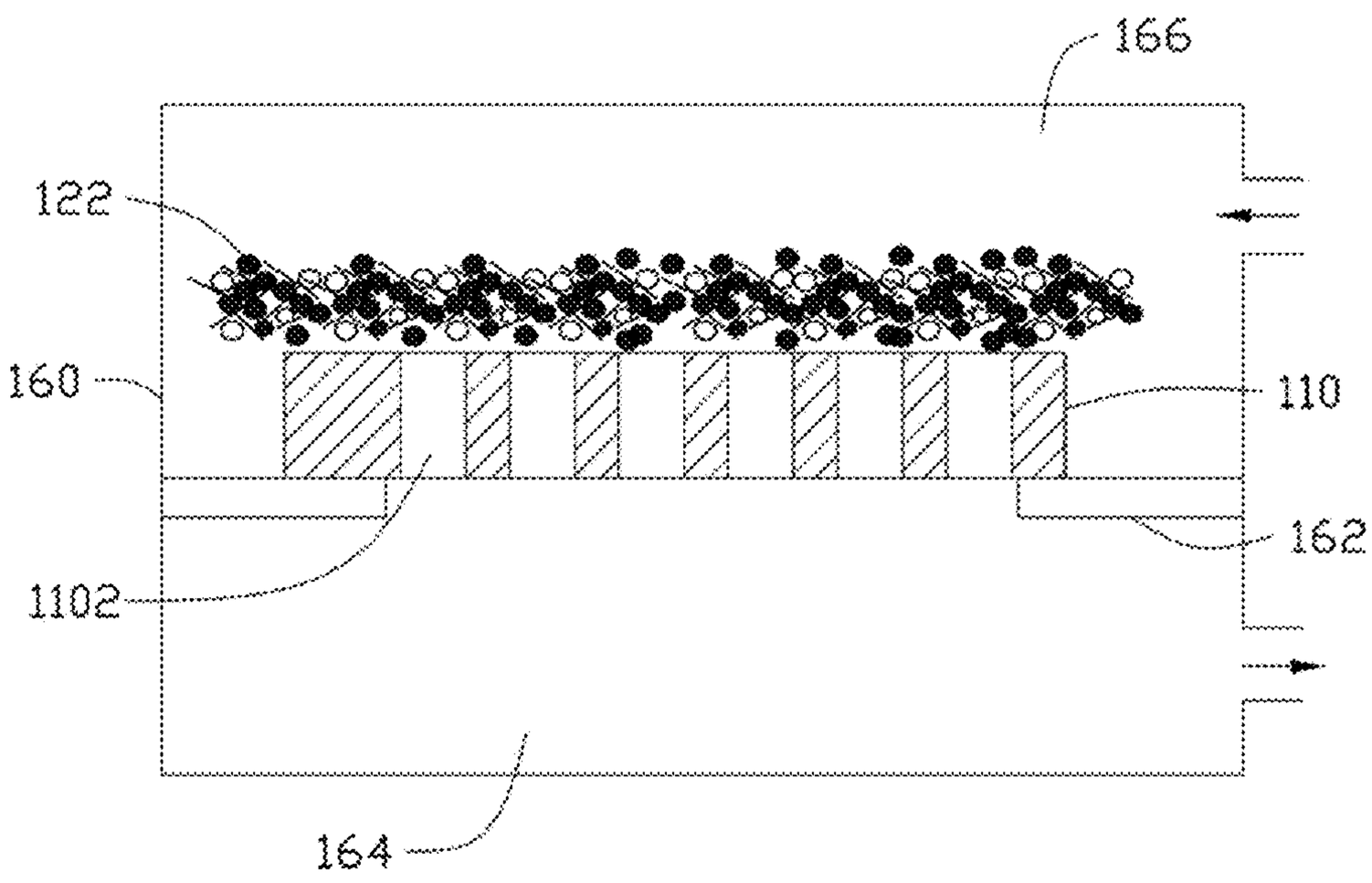


FIG. 14

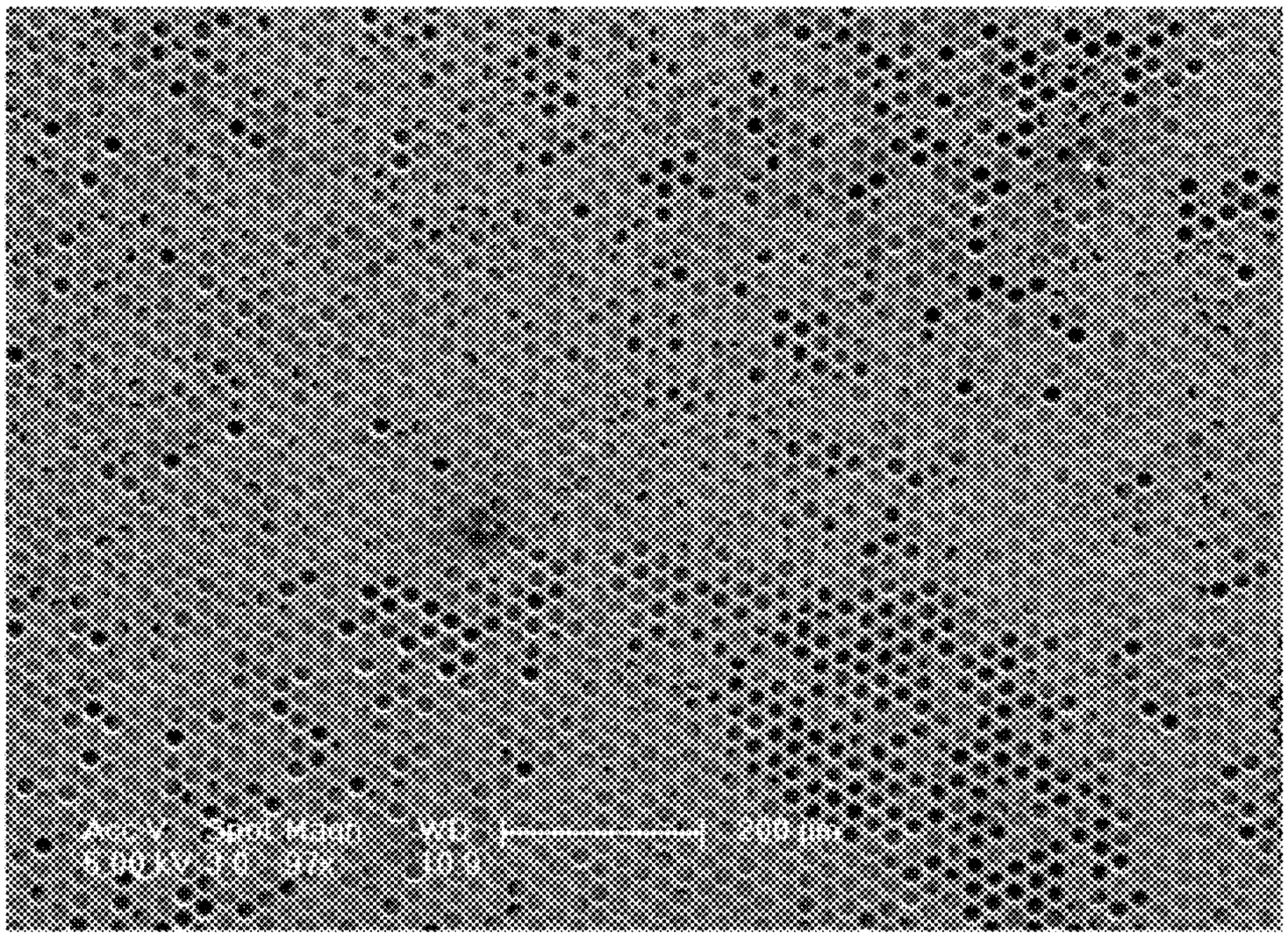


FIG. 15

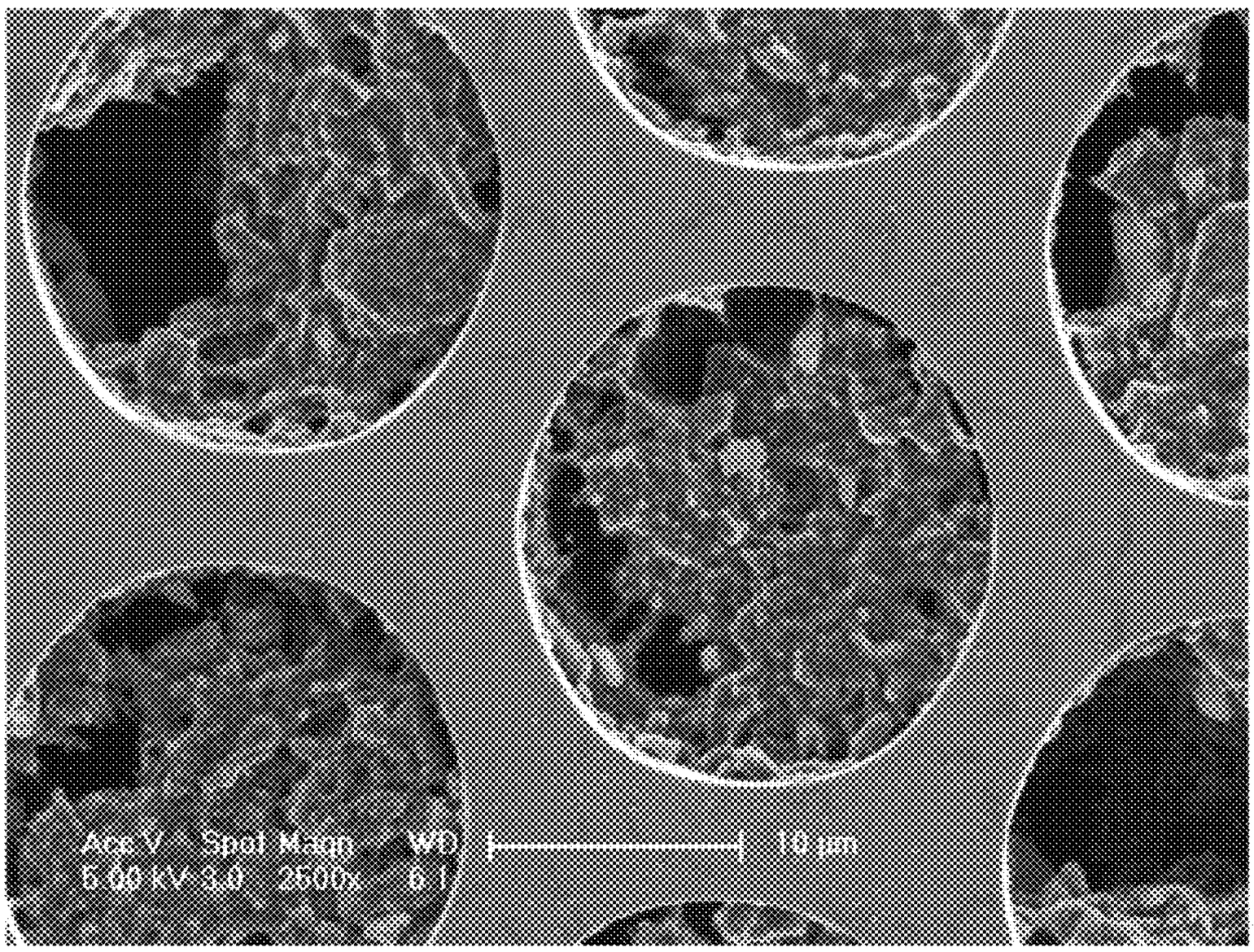


FIG. 16

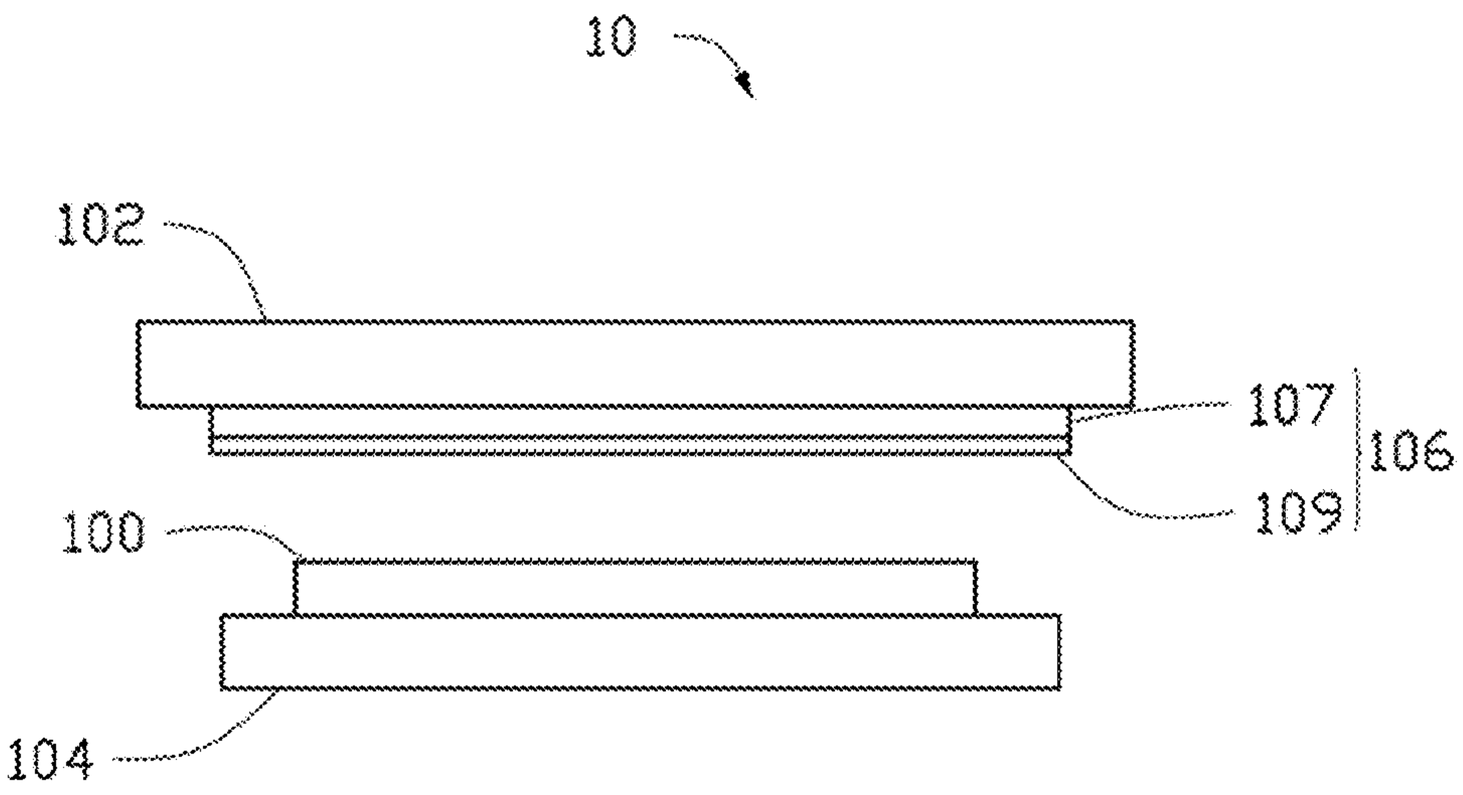


FIG. 17

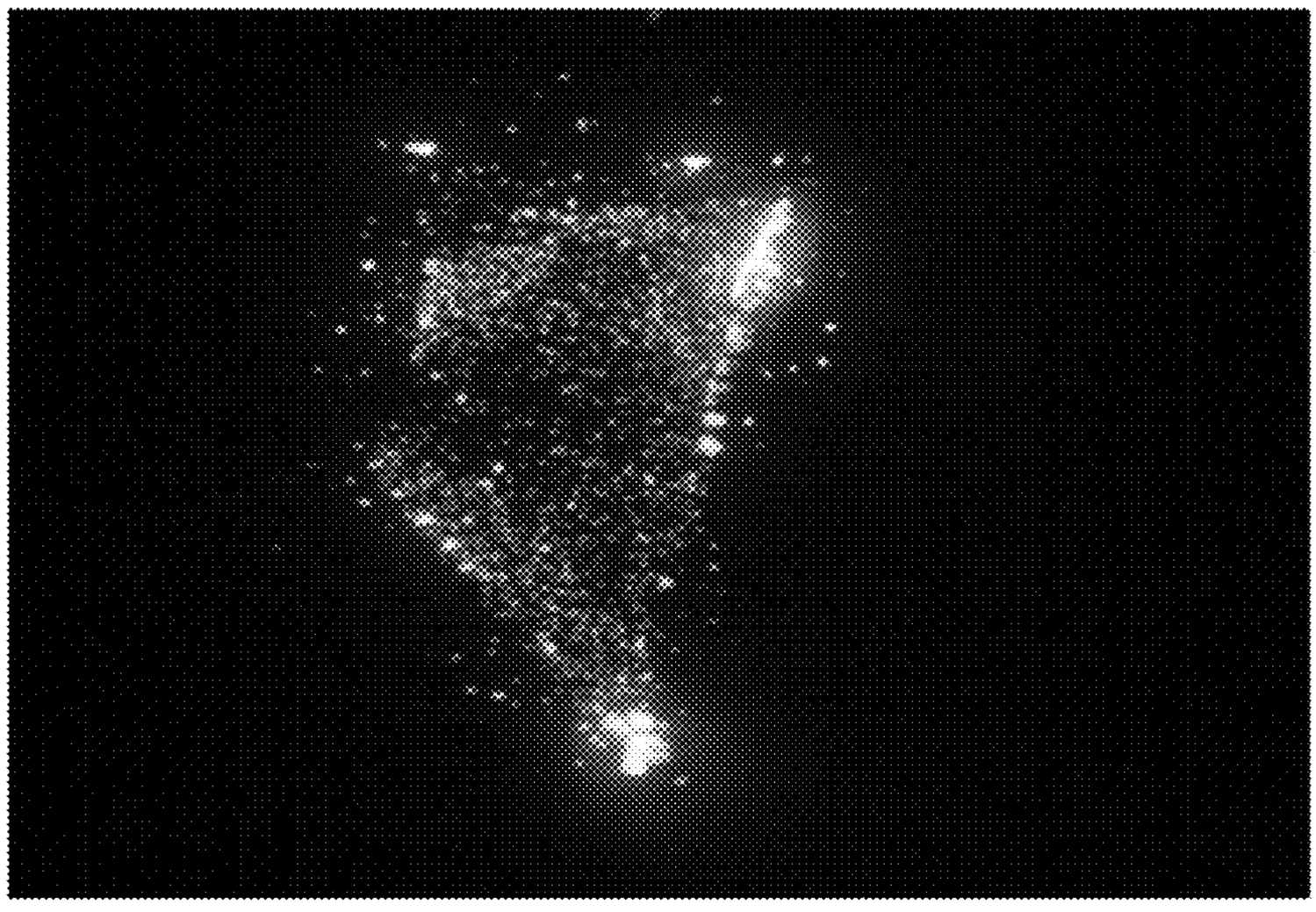


FIG. 18

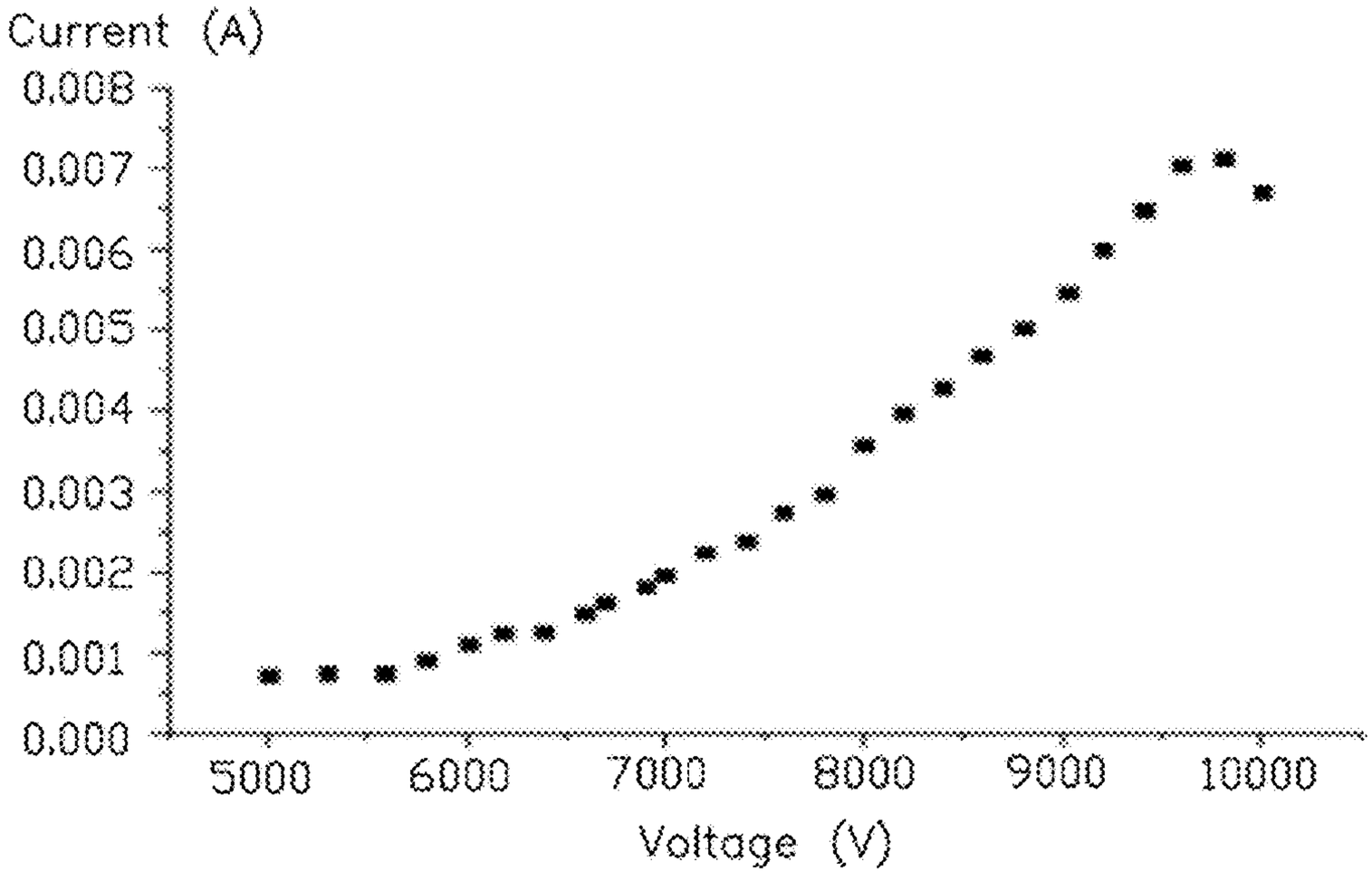

Current (A)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
5000
6000
7000
8000
9000
10000
Voltage (V)

FIG. 19

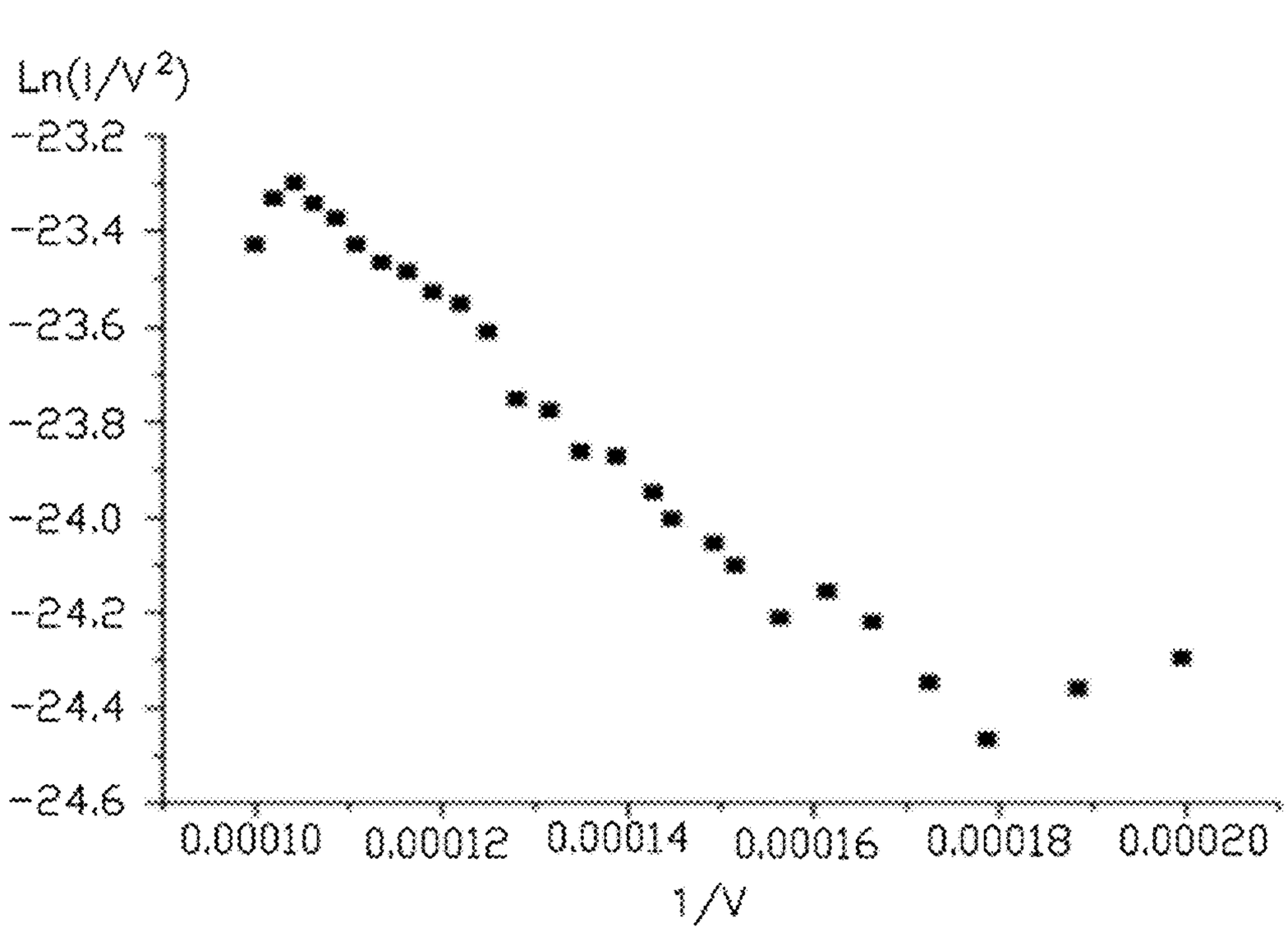
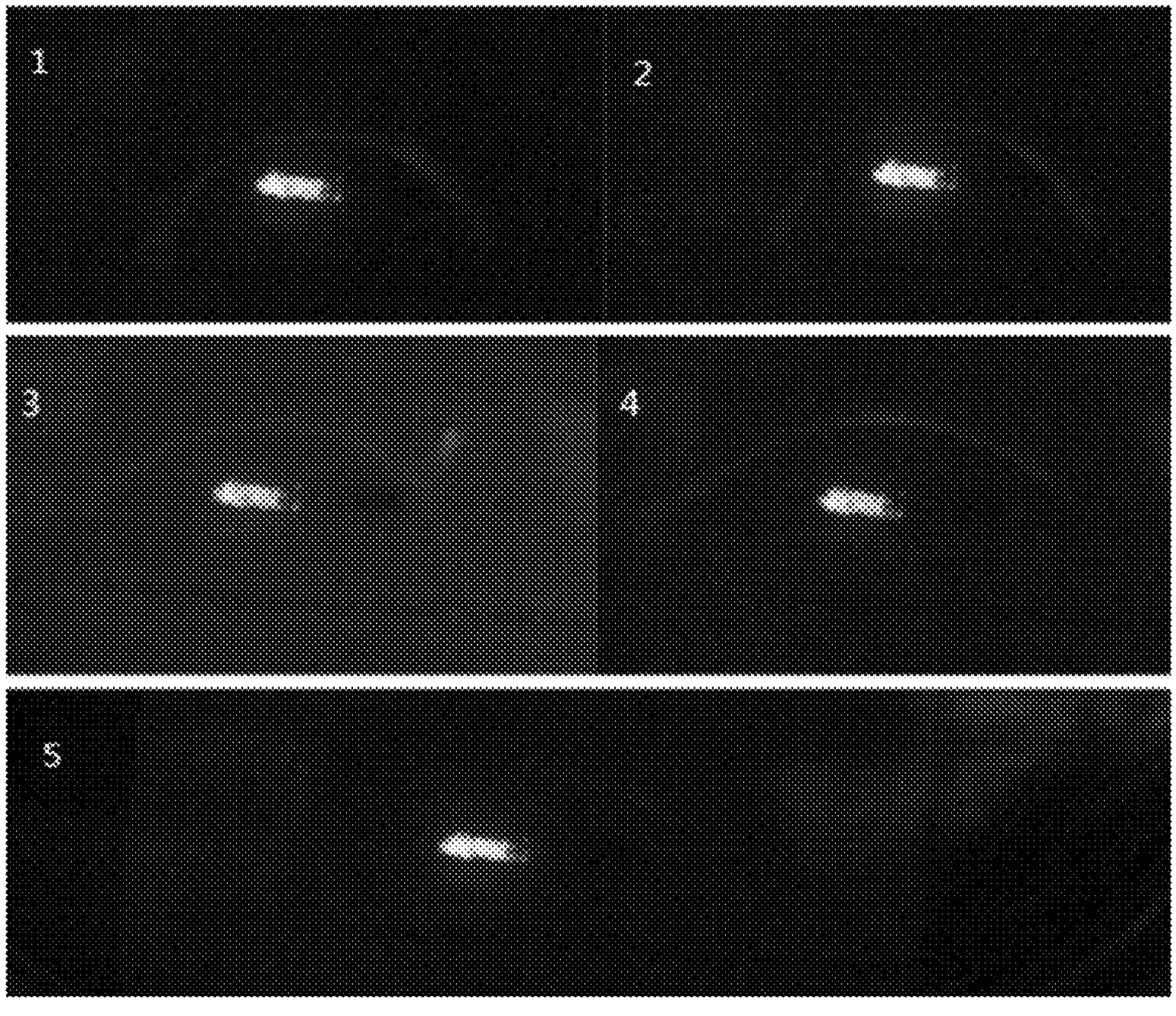

Ln(I/V 2)
-23.2
-23.4
-23.6
-23.8
-24.0
-24.2
-24.4
-24.6
0.00010
0.00012
0.00014
0.00016
0.00018
0.00020
1/V

FIG. 20



Anode spots under different vacuum pressures
1. $2.5*10^{-5}$ pa
2. $1.5*10^{-4}$ pa
3. $5.0*10^{-4}$ pa
4. $1.2*10^{-2}$ pa
5. $4.5*10^{-2}$ pa

FIG. 21

FIELD EMISSION CATHODE AND FIELD EMISSION DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims all benefits accruing under 35 U.S.C. §119 from China Patent Application No. 201410327705.4, filed on Jul. 10, 2014, in the China Intellectual Property Office, disclosure of which is incorporated herein by reference.

FIELD

The subject matter herein generally relates to field emission cathodes and field emission devices, in particular, to field emission cathodes and field emission devices based on carbon nanotubes.

BACKGROUND

Field emission display (FED) is a new, rapidly developing flat panel display technology. Generally, FED can be roughly classified into diode and triode structures. In particular, carbon nanotube-based FED have attracted much attention in recent years.

Field emission cathode is important element in FED. A field emission cathode based on carbon nanotubes usually includes an insulating substrate, a cathode electrode attached on the substrate, a number of carbon nanotubes distributed on the cathode electrode. Usually, the carbon nanotubes are fabricated on the cathode electrode by printing carbon nanotube slurry or carbon nanotube ink. However, the carbon nanotubes fabricated by printing are not secured on the cathode electrode. Thus, the carbon nanotubes tend to be pulled out from the cathode electrode by a strong electric field force causing the field emission cathode to have a short life.

What is needed, therefore, is to provide a field emission cathode based on carbon nanotubes for solving the problem discussed above.

BRIEF DESCRIPTION OF THE DRAWINGS

Implementations of the present technology will now be described, by way of example only, with reference to the attached figures, wherein:

FIG. **1** is a schematic view of a field emission cathode of example 1.

FIG. **2** is a cross-sectional view along line II-II of FIG. **1**.

FIG. **3** is a cross-sectional view of a field emission cathode of example 2.

FIG. **4** is a cross-sectional view of a field emission cathode of example 3.

FIG. **5** is a cross-sectional view of a field emission cathode of example 4.

FIG. **6** is a cross-sectional view of a field emission cathode of example 5.

FIG. **7** is a cross-sectional view of a field emission cathode of example 6.

FIG. **8** is a cross-sectional view of a field emission cathode of example 7.

FIG. **9** is a cross-sectional view of a field emission cathode of example 8.

FIG. **10** is a cross-sectional view of a field emission cathode of example 9.

FIG. **11** is a cross-sectional view of a field emission cathode of example 10.

FIG. **12** is a flowchart of one embodiment of a method for making a field emission cathode.

FIG. **13** is a schematic view of one embodiment of an immersing method for filling a microchannel plate with a carbon nanotube slurry.

FIG. **14** is a schematic view of one embodiment of a pressing method for filling a microchannel plate with a carbon nanotube slurry.

FIG. **15** is a photo image of one embodiment of a microchannel plate filled with carbon nanotube slurry and treated by heating.

FIG. **16** is a partially enlarged photo image of the FIG. **15**.

FIG. **17** is a schematic view of one embodiment of a field emission device.

FIG. **18** is a photo image of one embodiment of anode spots of a field emission device.

FIG. **19** is an I-V relationship of one embodiment of a field emission device.

FIG. **20** is a FN curve of one embodiment of a field emission device.

FIG. **21** is photo images of anode spots under different vacuum pressures.

DETAILED DESCRIPTION

It will be appreciated that for simplicity and clarity of illustration, where appropriate, reference numerals have been repeated among the different figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the embodiments described herein. However, it will be understood by those of ordinary skill in the art that the embodiments described herein can be practiced without these specific details. In other instances, methods, procedures and components have not been described in detail so as not to obscure the related relevant feature being described. The drawings are not necessarily to scale and the proportions of certain parts may be exaggerated to better illustrate details and features. The description is not to be considered as limiting the scope of the embodiments described herein.

Several definitions that apply throughout this disclosure will now be presented.

The term "coupled" is defined as connected, whether directly or indirectly through intervening components, and is not necessarily limited to physical connections. The connection can be such that the objects are permanently connected or releasably connected. The term "outside" refers to a region that is beyond the outermost confines of a physical object. The term "inside" indicates that at least a portion of a region is partially contained within a boundary formed by the object. The term "substantially" is defined to be essentially conforming to the particular dimension, shape or other word that substantially modifies, such that the component need not be exact. For example, substantially cylindrical means that the object resembles a cylinder, but can have one or more deviations from a true cylinder. The term "comprising" means "including, but not necessarily limited to"; it specifically indicates open-ended inclusion or membership in a so-described combination, group, series and the like. It should be noted that references to "an" or "one" embodiment in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

References will now be made to the drawings to describe, in detail, various embodiments of the present field emission cathodes and field emission devices.

Referring to FIGS. **1-11**, a field emission cathode **100** of one embodiment includes a microchannel plate **110** and a plurality of cathode emitters **120**. The microchannel plate **110** includes a first surface **1104** and a second surface **1106**, opposite to the first surface **1104**. The microchannel plate **110** defines a plurality of holes **1102**. Each of the plurality of holes **1102** extends from the first surface **1104** to the second surface **1106** to get through the microchannel plate **110**. The plurality of cathode emitters **120** are filled in the plurality of holes **1102** and electrically connected with the microchannel plate **110**. The plurality of cathode emitters **120** are in direct contact with and fixed on inner walls of the plurality of holes **1102**.

The microchannel plate **110** can be a conductor, a semiconductor or an insulator. The conductor can include material such as metal, alloy or other conductive materials. The semiconductor can include material such as silicon, gallium nitride or gallium arsenide. The insulator can include material such as silicon oxide, silicon nitride, silicon carbide, metal oxide, metal nitride, metal carbide, glass, ceramics or quartz. The microchannel plate **110** is a free-standing structure. The term "free-standing structure" means that the microchannel plate **110** can sustain the weight of itself when it is hoisted by a portion thereof without any significant damage to its structural integrity. The microchannel plate **110** is different from a layer or a film which is formed on a support by film technology such as spraying, spinning or sputtering, and cannot exist as a layer or film without the support. Especially, the microchannel plate **110** is different from the insulating layer fabricated by spinning coating and lithography. The shape, size and thickness of the microchannel plate **110** are not limited and can be selected according to need. For example, the microchannel plate **110** can be a square or rectangle plate and has a thickness above 100 micrometers.

Each of the plurality of holes **1102** can extend along a direction perpendicular with the first surface **1104**. The extending direction of the hole **1102** and the first surface **1104** can form an angle α, where $30° < \alpha$ 90°. In one embodiment, 45° α 60°. The diameter of the hole **1102** can be in a range from about 5 micrometers to about 200 micrometers. The distance between adjacent holes **1102** can be in a range from about 2 micrometers to about 200 micrometers. In one embodiment, the diameter of the hole **1102** is in a range from about 10 micrometers to about 40 micrometers, and the distance between adjacent holes **1102** is in a range from about 2 micrometers to about 10 micrometers. The microchannel plate **110** can be a double-layer structure or multi-layer structure. The holes **1102** of different layers are aligned as shown in FIG. **5**.

Furthermore, as shown in FIG. **3**, if the microchannel plate **110** is made of insulative material, the inner walls of the plurality of holes **1102** can be coated with a conductive layer **1109** to improve the conductivity of the microchannel plate **110** or allow the plurality of cathode emitters **120** to electrically connect to the cathode electrode **130**. The conductive layer **1109** can be a metal layer, alloy layer or indium tin oxide (ITO) layer.

Furthermore, as shown in FIG. **5**, the inner walls of the plurality of holes **1102** can be coated with a secondary electron layer **1108** so that to emit more field emission electrons. The secondary electron layer **1108** can includes material such as magnesium oxide, beryllium oxide, barium oxide, calcium oxide or cesium.

The plurality of cathode emitters **120** includes a plurality of carbon nanotubes **1202**. The plurality of carbon nanotubes **1202** are combined with each other by van der Waals attractive force therebetween. The plurality of cathode emitters **120** are located in the plurality of holes **1102**. At least some ends of the plurality of carbon nanotubes **1202** are exposed from the plurality of cathode emitters **120** and stands up to be used as electrons emission portions. The electrons emission portions are suspended and located in the plurality of holes **1102**, but the electrons emitted from the electrons emission portions can move out of the microchannel plate **110** from the second surface **1106**.

The plurality of cathode emitters **120** can also includes a plurality of conductive particles **1204**. The plurality of conductive particles **1204** can be metal particles or ITO particles. The metal particles can be metal particles with low melting point such as tin particles, lead particles, zinc particles or magnesium particles. The metal particles can be metal particles with high melting point and high chemical stability such as gold particles, silver particles, copper particles, or iron particles.

The plurality of cathode emitters **120** can also includes an inorganic bonding material (not shown). The bonding material can be made of a low-temperature glass powder by melting and cooling.

Different examples of the field emission cathodes are provided below.

EXAMPLE 1

Referring to FIGS. **1-2**, in the field emission cathode **100** of example 1, the microchannel plate **110** is a copper plate with a length of about 5 millimeters, a width of about 1.2 millimeters and a thickness of about 1 millimeter. The first surface **1104** and the second surface **1106** are substantially parallel with each other. The extending direction of the plurality of holes **1102** is perpendicular with the first surface **1104**. The diameters of the plurality of holes **1102** are about 20 micrometers, and the distance between adjacent holes **1102** is about 5 micrometers. The plurality of cathode emitters **120** are located in the plurality of holes **1102** and fixed on the inner wall of the plurality of holes **1102**. The plurality of cathode emitters **120** includes a plurality of carbon nanotubes **1202** and a plurality of conductive particles **1204**. The plurality of carbon nanotubes **1202** do not extend out of the plurality of holes **1102**. The field emission cathode **100** is free of special cathode electrode because the microchannel plate **110** is conductive and can be used as the cathode electrode. The electrons emitted from the carbon nanotubes **1202** will move for a period in the plurality of holes **1102** before getting out of the microchannel plate **110** from the second surface **1106**. Part of the electrons emitted from the carbon nanotubes **1202** will collide and bombard the inner wall of the plurality of holes **1102** to generate secondary electrons. Thus, the electrons emission efficiency of the field emission cathode **100** is improved.

EXAMPLE 2

Referring to FIG. **3**, the field emission cathode **200** of example 2 is similar with the field emission cathode **100** of example 1 except that the microchannel plate **110** is an insulative glass plate, and the inner walls of the plurality of holes **1102** and the first surface **1104** are coated with an aluminum conductive layer **1109**. The aluminum conductive layer **1109** can be continuous and used as cathode electrode.

EXAMPLE 3

Referring to FIG. **4**, the field emission cathode **300** of example 3 is similar with the field emission cathode **100** of example 1 except that the extending direction of the plurality of holes **1102** and the first surface **1104** form an angle α, where α=45°. Because the extending direction of the plurality of holes **1102** and the first surface **1104** form an angle α, the electrons emitted from the carbon nanotubes **1202** will have more chance to collide and bombard the inner wall of the plurality of holes **1102** to generate more secondary electrons. Thus, the electrons emission efficiency of the field emission cathode **100** is improved.

EXAMPLE 4

Referring to FIG. **5**, the field emission cathode **400** of example 4 is similar with the field emission cathode **100** of example 1 except that a second microchannel plate **140** is located on the second surface **1106** of the microchannel plate **110**. The second microchannel plate **140** defines a plurality of second holes **1402**. The plurality of second holes **1402** are through holes and aligned with the plurality of holes **1102** one by one. The extending direction of the plurality of second holes **1402** and the second surface **1106** form an angle β, where 30°<β 90°. In one embodiment, 45° β 60°. Furthermore, the inner walls of the plurality of second holes **1402** are coated with a magnesium oxide secondary electron layer **1108** so that to emit more field emission electrons. This structure allow the electrons emitted from the carbon nanotubes **1202** have more chance to collide and bombard the inner wall of the plurality of second holes **1402** to generate more secondary electrons. Thus, the electrons emission efficiency of the field emission cathode **100** is improved.

EXAMPLE 5

Referring to FIG. **6**, the field emission cathode **500** of example 5 is similar with the field emission cathode **100** of example 1 except that the microchannel plate **110** is a glass plate, and further a cathode electrodes **130** is located on the first surface **1104** of the microchannel plate **110** and electrically connected to the plurality of cathode emitters **120**. The plurality of cathode emitters **120** are uniformly dispersed in the plurality of holes **1102** and fixed on the inner walls of the plurality of holes **1102** by solidifying carbon nanotube slurry.

EXAMPLE 6

Referring to FIG. **7**, the field emission cathode **600** of example 6 is similar with the field emission cathode **500** of example 5 except that a magnesium oxide secondary electron layer **1108** is coated on the inner walls of the plurality of holes **1102**.

EXAMPLE 7

Referring to FIG. **8**, the field emission cathode **700** of example 7 is similar with the field emission cathode **600** of example 6 except that the extending direction of the plurality of holes **1102** and the first surface **1104** form an angle α, where α=60°.

EXAMPLE 8

Referring to FIG. **9**, the field emission cathode **800** of example 8 is similar with the field emission cathode **700** of example 7 except that a second microchannel plate **140** is located on the second surface **1106** of the microchannel plate **110**. The second microchannel plate **140** defines a plurality of second holes **1402**. The plurality of second holes **1402** are through holes and aligned with the plurality of holes **1102** one by one. The extending direction of the plurality of second holes **1402** is the same as the extending direction of the plurality of holes **1102**. The magnesium oxide secondary electron layer **1108** is coated both on the inner walls of the plurality of holes **1102** and the plurality of second holes **1402**.

EXAMPLE 9

Referring to FIG. **10**, the field emission cathode **900** of example 9 is similar with the field emission cathode **500** of example 5 except that a gate electrode **1110** is located on the second surface **1106** of the microchannel plate **110**. The gate electrode **1110** can be a free standing metal mesh or a deposited metal film. Parts of the gate electrode **1110** can extend to be suspended above the plurality of holes **1102** and define a plurality of through holes to allow the electrons to get through. The gate electrode **1110** can allow the field emission cathode **900** have a lower electron emission voltage. In example 9, the gate electrode **1110** is a copper mesh.

EXAMPLE 10

Referring to FIG. **11**, the field emission cathode **1000** of example 10 is similar with the field emission cathode **500** of example 5 except that the cathode electrode **130** is a patterned copper film, such as a plurality of copper strips parallel with and spaced from each other.

Furthermore, a method for making the field emission cathodes above is provided below. Referring to FIG. **12**, the method includes following steps:

step (S**10**), providing a microchannel plate **110**, wherein the microchannel plate **110** includes a first surface **1104** and a second surface **1106**, opposite to the first surface **1104**, and defines a plurality of holes **1102** extending through the microchannel plate **110** from the first surface **1104** to the second surface **1106**; and

step (S**11**), filling the plurality of holes **1102** with carbon nanotube slurry **122** and solidifying the carbon nanotube slurry **122**.

In step (S**10**), the microchannel plate **110** can be any microchannel plate **110** described above. In one embodiment, the microchannel plate **110** is a glass plate with a length of about 5 millimeters, a width of about 1.2 millimeters and a thickness of about 1 millimeter. The diameters of the plurality of holes **1102** are about 20 micrometers, and the distance between adjacent holes **1102** is about 5 micrometers.

Furthermore, the step (S**10**) includes depositing a secondary electron layer **1108** or a conductive layer **1109** on the inner walls of the plurality of holes **1102**.

In step (S**11**), the carbon nanotube slurry **122** includes at least carbon nanotubes and organic carrier. After filling the plurality of holes **1102** with carbon nanotube slurry **122**, the carbon nanotube slurry **122** are adhered on the inner walls of the plurality of holes **1102**.

The carbon nanotubes can be single-walled carbon nanotubes, double-walled carbon nanotubes, multi-walled carbon nanotubes, and combinations thereof The diameter of each single-walled carbon nanotube can range from about 0.5 nanometers to about 50 nanometers. The diameter of each double-walled carbon nanotube can range from about 1

nanometer to about 50 nanometers. The diameter of each multi-walled carbon nanotube can range from about 1.5 nanometers to about 50 nanometers. The length of the carbon nanotubes can be larger than 1 micrometer. In one embodiment, the length of the carbon nanotubes is in a range from about 5 micrometers to about 15 micrometers.

The organic carrier is a volatilizable organic material and can be removed by heating. The organic carrier can is a mixture of ethyl cellulose, terpineol, and ethanol. The weight ratio of the ethyl cellulose can be in a range from about 10% to about 40%, the weight ratio of the terpineol can be in a range from about 30% to about 50%, and the weight ratio of the ethanol can be in a range from about 30% to about 50%. The ethyl cellulose is a stabilizer and has strong polarity and can combine with the plasticizer to form a network structure or chain structure to enhance the viscosity and plasticity of the carbon nanotube slurry **122**. The terpineol is a diluent and can dissolve the stabilizer and allows the carbon nanotube slurry **122** to have liquidity. The ethanol is a solvent and used to disperse the carbon nanotubes.

The weight ratio of the carbon nanotubes can be in a range from about 2% to about 5%, and the weight ratio of the organic carrier can be in a range from about 95% to about 98%. In one embodiment, the weight ratio of the carbon nanotubes can be in a range from about 2.5% to about 3%, and the weight ratio of the organic carrier can be in a range from about 97% to about 98% so that the carbon nanotube slurry **122** has good liquidity and can be filled in the plurality of holes **1102** easily. Also, the carbon nanotube slurry **122** has good plasticity and can be uniformly dispersed in the plurality of holes **1102**. The viscosity of the carbon nanotube slurry **122** can be in a range from about 10 Pa·s to about 12 Pa·s at a shear rate of about 10 second-1. In one embodiment, the viscosity of the carbon nanotube slurry **122** is in a range from about 10 Pa·s to about 11 Pa·s at a shear rate of about 10 second-1 so that the carbon nanotube slurry **122** can be filled in and adhered to the inner walls of the plurality of holes **1102** easily.

Furthermore, the carbon nanotube slurry **122** can include conductive particles, such as metal powder. The average diameter of the conductive particles can be less than or equal to 1 micrometer, and the specific surface area of the conductive particles can be in a rang from about 1 m2/g to about 3 m2/g.

Furthermore, the carbon nanotube slurry **122** can include glass powder. The glass powder can be a low melting point glass powder with a melting point in a range from about 300° C. to about 600° C. The effective diameter of the glass powder can be less than or equal to 1 micrometer.

If the carbon nanotube slurry **122** further includes both the conductive particles and the glass powder, the weight ratio of the carbon nanotubes can be in a range from about 2% to about 5%, the weight ratio of the conductive particles can be in a range from about 2% to about 4%, the weight ratio of the glass powder can be in a range from about 1% to about 3%, and the weight ratio of the organic carrier can be in a range from about 88% to about 95%.

Referring to FIG. **13**, the plurality of holes **1102** can be filled with the carbon nanotube slurry **122** by immersing. In one embodiment, the filling the plurality of holes **1102** with carbon nanotube slurry **122** includes following substeps:

placing the microchannel plate **110** above the carbon nanotube slurry **122** in a container **150**; and

immersing the microchannel plate **110** in the carbon nanotube slurry **122** by pressing so that some of the carbon nanotube slurry **122** to fill in the plurality of holes **1102**.

Referring to FIG. **14**, the plurality of holes **1102** can also be filled with the carbon nanotube slurry **122** by pressing. In one embodiment, the filling the plurality of holes **1102** with carbon nanotube slurry **122** includes following substeps:

coating the carbon nanotube slurry **122** on a surface of the microchannel plate **110**;

placing the microchannel plate **110** with the carbon nanotube slurry **122** in a chamber **160** to divide the chamber **160** in to a first room **164** under the microchannel plate **110** and a second room **166** above the microchannel plate **110**; and

filling the carbon nanotube slurry **122** in the plurality of holes **1102** by exhausting gas from the first room **164** or filling gas in the second room **166**.

The chamber **160** includes a support **162** therein, and the microchannel plate **110** is located on the support **162**. The support **162** defines a through hole so that the plurality of holes **1102** to be suspended.

In step (S**11**), the carbon nanotube slurry **122** can be solidified by heating the microchannel plate **110** to a temperature in a range from about 150° C. to about 500° C. In one embodiment, the microchannel plate **110** is heated to a temperature in a range from about 150° C. to about 300° C.

Before heating, the carbon nanotubes **1202** of the carbon nanotube slurry **122** are connected to form a net and uniformly dispersed in the organic carrier. The ends of some carbon nanotubes **1202** are free ends. The carbon nanotube slurry **122** are adhered to the inner surface of the plurality of holes **1102** by surface tension, and the carbon nanotubes **1202** are combined with each other by the organic carrier. The organic carrier will be volatilized during heating. Thus, the surface tension between the carbon nanotube slurry **122** and the inner surface of the plurality of holes **1102** will be replaced by the van der Waals attractive force between the carbon nanotubes **1202** and the inner surface of the plurality of holes **1102**. After heating, the carbon nanotubes **1202** will be joined together and fixed on the inner surface of the plurality of holes **1102** only by the van der Waals attractive force therebetween. The free ends of the carbon nanotubes **1202** will stand up and be used as electrons emission portions.

In one embodiment, the carbon nanotube slurry **122** includes low melting point glass powder or low melting point metal powder. The low melting point glass powder or low melting point metal powder will be melted during the heating and solidified during cooling to bonder the carbon nanotubes **1202** together and fix the carbon nanotubes **1202** on the inner surface of the plurality of holes **1102** firmly.

Furthermore, a process of centrifugal movement or oscillation can be performed on the microchannel plate **110** during or after heating so that the carbon nanotube slurry **122** to be adhere on the inner surface of the plurality of holes **1102** closely.

As shown in FIGS. **15-16**, after heating, the carbon nanotube slurry **122** is uniformed filled in the plurality of holes **1102** of microchannel plate **110**.

Furthermore, if the microchannel plate **110** is an insulative plate, a step (S**12**) of applying a cathode electrode **130** on the first surface **1104** can be performed. The cathode electrode **130** is electrically connected with the carbon nanotubes **1202**. The cathode electrode **130** can be a conductive film formed by electroplating or electroless plating. Thus, the cathode electrode **130** will be filled in the plurality

of holes **1102**. The cathode electrode **130** can also be a free standing plate such as metal sheet or ITO glass. In one embodiment, the cathode electrode **130** is a copper sheet.

Furthermore, if the microchannel plate **110** is an insulative plate, a step of applying a gate electrode **1110** on the second surface **1106** can be performed. The gate electrode **1110** can be a conductive film formed by electroplating or electroless plating.

Furthermore, a step of applying a second microchannel plate **140** on the second surface **1106** can be performed.

Referring to FIG. **17**, in one embodiment, a field emission device **10** using the field emission cathodes above is provided. The field emission device **10** includes an anode substrate **102**, a cathode substrate **104** spaced from the anode substrate **102**, an anode structure **106** located on the anode substrate **102** and the field emission cathode **100** located on the cathode substrate **104** and spaced from the anode structure **106**.

The cathode substrate **104** can be a glass plate, ceramic plate, or a silicon plate. The anode substrate **102** can be a transparent plate such as a glass plate. In one embodiment, both the cathode substrate **104** and the anode substrate **102** is glass plate.

The anode structure **106** includes an anode electrode **107** located on the anode substrate **102**. The anode electrode **107** can be a transparent film such as an ITO film. Furthermore, the anode structure **106** can include a fluorescent layer **109** located on the anode electrode **107** so that the field emission device **10** can be used as a field emission display.

The field emission properties of the field emission device **10** is tested in a vacuum with a pressure of about 10−5 Pa. The distance between the field emission cathode **100** and the anode structure **106** is about 3 millimeters. Although the sparking occurs in some location many times, the whole field emission is not destroyed.

As shown in FIG. **18**, it can be seen that from the image of the screen and brightness, the field emission device **10** has a stable field emission property. Thus, the microchannel plate **110** has protected the cathode emitters **120** from being destroyed during sparking occurring in some location. If the ends of the carbon nanotubes extend out of in the plurality of holes **1102** and not protected by the microchannel plate **110**, the whole field emission property of the field emission device **10** will be destroyed even if sparking occurs in some location.

FIG. **19** is an I-V relationship of one embodiment of the field emission device **10**. As shown in FIG. **19**, the highest voltage pulse is about ten thousands volts, the frequency is about 50 Hz, the width is about 10 micrometers, and the current is obtained in the interval of about 200 volts. FIG. **20** is a FN curve of one embodiment of the field emission device **10**. As shown in FIG. **20**, the field emission cathode has a field emission property in accordance with the field emission characteristic. FIG. **21** is photo images of anode spots of the field emission device **10** under different vacuum pressures. The he highest voltage pulse is about eight thousands volts, and the width is about 10 micrometers. As shown in FIG. **21**, the field emission device **10** has substantially the same anode spots in both low and high vacuum pressures.

The embodiments shown and described above are only examples. Even though numerous characteristics and advantages of the present technology have been set forth in the foregoing description, together with details of the structure and function of the present disclosure, the disclosure is illustrative only, and changes may be made in the detail, including in matters of shape, size and arrangement of the parts within the principles of the present disclosure up to, and including, the full extent established by the broad general meaning of the terms used in the claims.

Depending on the embodiment, certain of the steps of methods described may be removed, others may be added, and the sequence of steps may be altered. The description and the claims drawn to a method may include some indication in reference to certain steps. However, the indication used is only to be viewed for identification purposes and not as a suggestion as to an order for the steps.

What is claimed is:

1. A field emission cathode, comprising:

a microchannel plate, wherein the microchannel plate is an insulative plate and comprises a first surface and a second surface, opposite to the first surface; and the microchannel plate defines a plurality of holes extending through the microchannel plate the from the first surface to the second surface; and the microchannel plate is a free-standing structure;

a cathode electrode located on the first surface; and

a plurality of cathode emitters, wherein the plurality of cathode emitters are filled in the plurality of holes and electrically connected with the cathode electrode.

2. The field emission cathode of claim **1**, wherein the microchannel plate comprise material selected from the group consisting of silicon oxide, silicon nitride, silicon carbide, metal oxide, metal nitride, metal carbide, glass, ceramics and quartz.

3. The field emission cathode of claim **1**, wherein the plurality of holes have substantially the same extending direction, and the first surface is substantially parallel with the second surface.

4. The field emission cathode of claim **3**, wherein the extending direction and the first surface form an angle α, where $30° < \alpha \leq 90°$.

5. The field emission cathode of claim **1**, wherein a diameter of each of the plurality of holes is in a range from about 10 micrometers to about 40 micrometers, and a distance between adjacent holes is in a range from about 2 micrometers to about 10 micrometers.

6. The field emission cathode of claim **1**, wherein inner walls of the plurality of holes are coated with secondary electron layer.

7. The field emission cathode of claim **1**, wherein the plurality of cathode emitters comprises a plurality of carbon nanotubes combined with each other by van der Waals attractive force therebetween.

8. The field emission cathode of claim **7**, wherein at least some ends of the plurality of carbon nanotubes are exposed from the plurality of cathode emitters and stands up.

9. The field emission cathode of claim **7**, wherein the plurality of carbon nanotubes are fixed on inner walls of the plurality of holes only by the van der Waals attractive force.

10. The field emission cathode of claim **1**, wherein the plurality of cathode emitters comprises a plurality of carbon nanotubes and a plurality of conductive particles.

11. The field emission cathode of claim **10**, wherein the plurality of conductive particles are metal particles or indium tin oxide particles.

12. The field emission cathode of claim **1**, wherein the plurality of cathode emitters comprises a plurality of carbon nanotubes and an inorganic bonding material, and the plurality of carbon nanotubes are bonded on inner walls of the plurality of holes by the inorganic bonding material.

13. The field emission cathode of claim **12**, wherein the inorganic bonding material is made of a low-temperature glass powder by melting and cooling.

14. A field emission cathode, comprising:

a first microchannel plate, wherein the first microchannel plate is an insulative plate and comprises a first surface and a second surface, opposite to the first surface; and the first microchannel plate defines a plurality of first holes extending through the first microchannel plate the from the first surface to the second surface;

a second microchannel plate located on the first surface, wherein the second microchannel plate defines a plurality of second holes extending through the second microchannel plate and aligned with the plurality of first holes; and each of the first microchannel plate and the second microchannel plate is a free-standing structure;

a cathode electrode located on the second surface; and

a plurality of cathode emitters, wherein the plurality of cathode emitters are filled in the plurality of first holes and electrically connected with the cathode electrode.

15. The field emission cathode of claim 14, wherein the plurality of second holes have substantially the same extending direction, and the first surface is substantially parallel with the second surface.

16. The field emission cathode of claim 15, wherein the extending direction and the first surface form an angle β, where $30° < \beta \leq 90°$.

17. The field emission cathode of claim 16, wherein the plurality of first holes extend along a direction substantially perpendicular with the first surface.

18. The field emission cathode of claim 14, wherein inner wall of the plurality of second holes are coated with secondary electron layer.

19. A field emission device, comprising: an anode substrate, a cathode substrate spaced from the anode substrate, an anode structure located on the anode substrate and a field emission cathode located on the cathode substrate and spaced from the anode structure;

wherein the field emission cathode comprises:

a microchannel plate, wherein the microchannel plate is an insulative plate and comprises a first surface and a second surface, opposite to the first surface; and the microchannel plate defines a plurality of first holes extending through the microchannel plate the from the first surface to the second surface; and the microchannel plate is a free-standing structure;

a cathode electrode located on the first surface; and

a plurality of cathode emitters, wherein the plurality of cathode emitters are filled in the plurality of first holes and electrically connected with the cathode electrode.

20. The field emission device of claim 19, wherein the field emission cathode further comprises a second microchannel plate located on the first surface, the second microchannel plate defines a plurality of second holes extending through the second microchannel plate and aligned with the plurality of first holes.

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